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The effect of high-frequency noise (up to 3000 cps) on the auditory analysor of human subjects was studied, at a total noise level of 60 - 76 decibels and exposure to noise up to 60 days, to determine the threshold value for life-support noise in manned spacecraft. Factors such as relative isolation, hypokinesia, restrictive clothing, capsule living conditions, and monotony of sound were taken into consideration. Continuous noise for 72 hrs raised the auditory threshold by 15 - 20 db and ten-day experiments resulted in an increase by 20 - 25 db with functional disorders of the auditory analysor after 10 days. Intermittent noise (up to 7 hrs/day) showed a cumulative effect only after months or years. A noise of 50 - 60 phons background for spacecraft cabins was found acceptable as both upper and lower limit, with too low a noise level considered harmful to the neuropsychic system.

Author

Among the numerous problems of space medicine, the problems of the influence of noise on the organism of the astronaut occupy a special position. The peculiarity of living conditions in spacecraft substantially modifies the nature and intensity of the external acoustic stimuli acting on the organism and in

* Numbers in the margin indicate pagination in the original foreign text.

particular on the human auditory analysor. From the viewpoint of the physical characteristics of noise and its pathophysiology, the influences of space travel may (arbitrarily) be divided into two stages. The first stage is characterized by the action of brief intense noise and corresponds to the active phase of the motion of rocket vehicles. A large number of studies have been published on the harmful effect of this type of noise on human subjects of various occupations. The character and degree of the general physiological and auditory disturbances have been studied in detail by such authors, the maximum threshold noise levels have been established, and the principles and means of protection have been determined.

The flights of Soviet astronauts on the "Vostok" and "Voskhod" have shown that individual means of protection against short-time intense noise will protect the subject from unpleasant auditory sensations and ensure the maintenance of adequate working fitness by establishing reliable screening from the masking noise in radio communication. The prospects of space travel lasting many months and even many years may include the use of vehicles that can be placed in orbit by more gradual acceleration. With such flight profiles, the time during /2 which high-intensity noise will act will be considerably increased, and the power will obviously also increase.

It is only natural that predicting the physical fitness of a human subject under such conditions will necessitate continued studies of the multilateral effect of high-intensity noise on the astronaut. Special studies of the reduction of noise at the source and selection of optimum sound-insulating and sound-absorbing materials for future vehicles, will likewise be necessary.

The second stage of a space flight is characterized by the continuous and prolonged action of noise of moderate and low intensity, and corresponds to the period of orbital motion of sputniks and spacecraft. During this stage, the major source of noise in the cabin are the units of the life-support system which, in view of the flight conditions themselves, must operate continuously and produce a constant acoustic background in the cabin.

The problem of the habitability of spacecraft cabins during prolonged orbital flight cannot be solved without experimental definition of the threshold values of the noise constantly acting on the astronaut. Although studies on the normalization of high-intensity noise have a long history and produced extensive experimental material, the problems of the pathophysiology of the action and normalization of moderate and low-intensity noise under orbital flight conditions have arisen only in the last few years. In a space flight lasting several weeks or months, the factor of continuity of the acoustic effect will become even more important. This demands the search for new ways and means of justifying the permissible noise levels in a spacecraft cabin.

The regulation of the noise parameters, as is commonly known, depend on the design of the spacecraft, the fundamental problems and features of the flight, and on the type of activity of the astronaut.

On craft without special compartments for sleep and rest, the allowable noise level should approach the threshold recommended for dwellings. According to the data of several authors, the noise level in dwellings should not exceed 35 - 40 db by day and 25 - 30 db by night. I.L.Karagodina (1962) considers that the optimum noise level at a frequency of 1000 cps during the day is 35 db, and 30 db at night. Similar levels are recommended by other authors for space travel. According to E.B.Konecci, the allowable levels of continuous and prolonged noise during flight should not exceed 40 db (1960). Ursula Slager, in a survey of space medicine published in 1963, likewise states that the noise level in the cabin during the period of orbital flight should, if possible, not exceed 40 db.

Unfortunately, the results of studies on the allowable noise levels in /3
dwellings cannot be directly applied to spacecraft cabins, since these standards do not take account of the effect of factors of relative isolation, hypokinesia, and the like. The data by E.B.Konecci and Ursula Slager are not based on experimental data obtained in prolonged stay of a subject in a cabin of small volume.

Special studies were made to provide physiological-hygienic bases for defining the threshold of noise acting on an astronaut around the clock and continuously during flight. In 92 experiments on 63 subjects we studied the effect of high-frequency noise (up to 3000 cps) on the human auditory analysor. The total noise level was 60 - 65 and 74 - 76 db, and the exposure was from 8 hrs to 60 days. We simulated not only the acoustic medium of the cabin but also a number of other flight factors: isolation, hypokinesia, working conditions, rest, food, clothing, etc.

The spectral and amplitude characteristics of the noise were determined by three methods:

measuring the total noise level by DOU sound-level meters;

registration of the amplitude-frequency components of the noise by a "Bruell and Kerr" microphone with simultaneous automatic analysis on a spectrograph of the same Company;

recording the noise through a microphone and a calibrated area on a ferromagnetic film, followed by its analysis on a "Bruell and Kerr" spectrograph taking account of the total level found on the noise meter.

The functional state of the auditory analysor was determined by varying the following parameters:

auditory threshold at frequencies of 125, 250, 500, 1000, 2000, 3000, 4000, 6000, 8000, and 10,000 cps by air conduction;

differential threshold in pitch from levels of 1000 cps;

masking threshold for a 1000 cps tone by white noise of 70 db intensity;

time for restoration of the initial auditory sensitivity after a standard three-minute load by white noise of 95 db intensity.

All methodological measures were modified to adapt them to the conditions of a stay of many days in a sealed cabin of small volume. In particular, to prevent the development of a time reflex in the subject, a special apparatus was designed to standardize the duration of the auditory signal (1 sec) and vary the interval between successive tones by a random law. The output voltages of the audiometer were calibrated against the oscillograph screen before the experiment, in order to be able to check the stability of the indices for any /4 day of a multi-day experiment.

The results of the study of the auditory threshold were statistically worked up both from the calculated confidence level and by the method of least squares (Ye.S.Venttsel', 1960). On questioning, the subjects complained of headache, ringing of the ears, poor sleep, and poor appetite which they subjectively attributed to the noise.

According to data by A.A.Arkad'yevskiy (1962) and E.L.Orlovskaya (1962), a seven-day exposure to high-frequency noise, at an overall level of 75 db, has no general detrimental effect on the human organism. Therefore, we thought it possible to start the first experimental series with this noise level in its effect on the human body, also taking account of the combined effect of prolonged stay in a sealed cabin of small volume.

We found that after eight hours of continuous noise of a total intensity of 74 - 76 db, a rise in the auditory threshold takes place by the end of the experiment, amounting to 4 - 5 db at low frequencies and 5 - 10 db at high frequencies. The time required to restore the initial auditory sensitivity, according to the differential thresholds, in pitch and in time of reverse adaptation, is from 1 to 2 hrs. The results indicate moderate fatigue of the auditory fuction.

In studies on the continuous action of these noises for 24 hrs, we noted a lowering of the auditory sensitivity during this period by 10 - 15 db at low frequencies and 10 - 20 db at high frequencies. The differential thresholds in pitch increased from 0.008 - 0.010 to 0.012 - 0.022. Restoration of the initial auditory sensitivity took place 1 - 2 hrs after the end of the noise. It is characteristic that the principal indices of the physiological functions (respiration, blood pressure, ECG elements) showed no substantial changes. Under these conditions, however, the subjects first complained of the irritating effect of noise during sleep and rest.

Continuous noise for 72 hrs raised the auditory threshold by 15 - 20 db. The differential pitch thresholds rose from 0.008 – 0.011 to 0.013 - 0.018. Restoration of auditory sensitivity took 2 - 3 hrs. Pulse, respiration, and blood pressure differed only slightly from the original values at the end of the experiment. The subjects complained of ringing in the ears and headache.

In ten-day experiments we found that the threshold of hearing fluctuated in various periods by 10.0 - 17.5 db. After the noise had stopped we found a rise in the auditory threshold by 20 - 25 db. The time of reverse adaptation increased from 35 - 40 to 240 - 300 sec. Restoration of the initial auditory sensitivity took 8 - 18 hrs. During the same period, the subjects were disturbed by headache, noise and ringing in the ears. The reaction of the cardiovascular system in response to the standard physical load was manifested in a /5 minor lowering of vascular tonus. Physiological examination showed symptoms of fatigue. Comparison of the results of acoumetry with the subjective complaints and the results of clinical-physiological examinations permit the conclusion as to a pronounced overall effect on the human organism of continuous noise (10 days) of 74 - 76 db intensity.

After 30 days of continuous high-frequency noise at 75 db, we found fluctuations of the auditory threshold, with a narrowing of the variational range of the period from the 5 - 7th and from the 24 - 27th day of the experiment. After the end of the experiment the auditory threshold had risen by 25 - 30 db. The reverse adaptation time increased by a factor of 3 - 5. Restoration of the initial auditory sensitivity took 48 - 50 hrs. A characteristic feature of these studies was the constant complaint, throughout the experiments, of the irritating and fatiguing effect of the noise. After prolonged action of the stimulus, the subjects had the sensation of continuous noise in the ear for one full day. The studies showed a decrease in amplitude and frequency of the EEG alpha rhythm by the end of the experiment, accompanied by diffuse slow waves. Control experiments, under relative isolation and hypokinesia, permitted the conclusion that continuous noise for 30 days has a pronounced harmful effect on the central nervous system and on the auditory analysor.

As a result of these investigations we found that continuous and intermittent applications of high-frequency noise at 75 db differ substantially in character of influence and in degree of change in the function of the auditory analysor. In the case of intermittent noise (up to 7 hrs per day), a cumulative effect is noted only after many months or years whereas, after continuous noise, such symptoms appear as early as the tenth day.

The resultant experimental data indicate the necessity of further study on a rational definition of constant acoustic background levels in spacecraft on long trips.

With this object, we started a second series of studies on the effect of high-frequency noise at an overall level of 60 - 65 db, acting continuously for up to 60 days. We found no significant changes in the function of the auditory analysor under these conditions. The greatest rise in the auditory threshold was noted in the first days of the experiment. Subsequently, against the background of a certain scattering of the auditory sensitivity threshold, we noted a tendency to a relative decline. When the results were worked up by the methods of least squares (the relation $y = ax + b$), the general trend of the hearing changes approximates a straight line asymptotically approaching the abscissa. /6
G.V.Gershuni, as long ago as 1949, mentioned the possibility of such reactions of the auditory system on transition to a new auditory medium. The slope of auditory sensitivity in experiments at noise levels of 60 - 65 db did not differ from the fluctuations of the auditory threshold in background experiments at levels not exceeding 35 - 40 db. The thresholds of masking, and the differential thresholds for pitch and adaptation time likewise did not exceed the usual physiological changes. The subjects, as a rule, did not complain of the overall unfavorable action of noise at 60 - 65 db during periods of sleep and rest. The indices of the principal physiological functions did not change under these conditions (A.G.Kuznetsov and N.A.Agadzhanyan, 1963; S.G.Zharov et al., 1963).

It is well known that not specially selected subjects often do not fully tolerate noise of even moderate intensity during sleep and rest (J.Grimaldi, 1957; I.L.Karagodina, 1962; Ye.V.Bobin, 1962; L.Ya.Skuratova, 1963). Consequently, we attributed our results to the high neuropsychic resistance of the subjects we had selected.

Based on our experiments we consider it acceptable to recommend a constant sound background of 60 - 65 db for spacecraft and exposures of up to 60 days (Yu.V.Krylov, 1965). Naturally, it is impossible to state today that the recommended noise levels are final since, for well-known reasons, the fundamental factor of space flight, namely, weightlessness, was not simulated in the ground experiments. On careful analysis, however, we find no substantial difference in the tolerance for noise by astronauts in ground tests and in space travel extending up to five days.

In spacecraft with separate compartments for work, sleep, and rest, one must differentiate the permissible noise levels, taking account of the specific purpose of each such compartment. In the section for sleep and rest, the maximum value of the noise in intensity and spectrum should not exceed the tolerance level of 60 - 65 db established by us. In the command section, where the astronaut must watch the navigation instruments for several hours at a time, voice-communicate with the crew members, etc., the noise level likewise should not significantly differ from the above values. In defining the noise levels in the operating cabins, allowance must be made for the type of activity and the length of stay. During a 4-hour watch, the astronaut evidently may be subjected to noise up to a total level of 85 db. In the auxiliary sections, visited periodically for short times by the astronaut, higher noise levels may be permitted.

At an acoustic stimulus exceeding 100 db, and again depending on the /7 amplitude and spectral composition, individual means of protection from noise are recommended.

The correct physiological-hygienic normalization of noise in the various compartments of a spacecraft will ensure adequate physical and work fitness of an astronaut during prolonged flight.

The peculiar conditions of space travel require not only the consideration of universally accepted propositions of rational physiological-hygienic normalization but also raise entirely new problems and methods of securing acoustic comfort in the cabin. Among other stimuli that inform the astronaut as to the course of the flight and the environmental conditions, the relative contribution and significance of auditory signals is greatly increased in space travel. For this reason, the usual physiological-hygienic aspect of the noise background is complemented by the extreme significance of the psychoacoustic effect of noise.

As already stated, the fundamental acoustic noise in the cabin during the entire flight is produced by the continuous operation of the units of the life-support system. This noise is characterized by considerable stability in amplitude and spectral components. In its psychoacoustic aspect, this noise takes on the character of a monotonous unpleasant stimulus.

The pronounced cyclic character and monotony of the stimuli on a long space trip generate the conditions for dominance of inhibitory processes in the neuropsychic system. In this connection, it would be wrong to reduce the noise levels in the cabin too much, i.e., to the level called "silence" in psychoacoustics. The necessity of regulating not only the permissible upper level of constant noise background in the cabin but also its permissible lower level, is another important point in the normalization of noise under conditions of prolonged space travel. For this reason, a new and highly important problem for such conditions is to exclude the unfavorable physiological and psychoacoustic effect of monotonous noise stimuli of moderate and low intensity. This problem has several aspects, some of which are not yet fully understood at the present state of the art. In our opinion, one of the major problems is to establish the relationship between the amplitude-frequency characteristics of the noise as a physical quantity and the loudness as the expression of a psychoacoustic effect.

The subjective sensation of loudness of sounds as perceived by the auditory organ depends not only on the sound-pressure level but also on its spectral composition, as shown by Fletcher and Manson and later by Robinson and Dadson et al. We may conclude from the results of their work that the loudness of pure tones is a direct function of intensity and that, in the region of low and moderate sound pressure, it also depends on the frequency of the signal. The /8
sensation of loudness of sounds with their complex spectrum (like most real noises) differs from the perception of pure tones. Various synthetic methods as proposed by Zwicker, 1956, 1959; Stevens, 1961; Beranek et al., 1951, 1957, 1960; and Niese, 1960, must be used in measuring the loudness of noises with a complex spectrum. These methods first determine the subjective psychoacoustic effect of a complex noise and then develop a principle of standardization. Envisaged is the determination of the loudness of a given noise in various frequency bands, the compilation of the resultant data with allowance for the perception characteristics of the auditory organ for various frequency components, and the determination of the masking effect evidently present in a complex spectrum. The loudness level is determined for each band from special Tables or graphs taking account of the equal-loudness curves and of the width of the filter.

On the basis of these methods, we believe that the amplitude-frequency characteristic of a constant noise background can be so modified that, at constant loudness, the monotony of this noise is eliminated.

Bearing this proposition in mind, we have experimentally established that a noise of 50 - 60 phons background may be considered allowable for the cabins of spacecraft.

The entire group of measures on the regulation not only of the permissible upper noise levels but also of the minimum levels, in combination with the development of measures to exclude the harmful psychoacoustic effect of prolonged continuous noise, must be considered as a single problem, namely, that of establishing an optimum acoustic background in spacecraft cabins for prolonged flights.

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